REPORT NUMBER: RED-08-02

REPORT ON EARLY DISTRESS (RED)

Investigation of PCC Pavement on STH 29

FINAL REPORT

WISCONSIN DEPARTMENT OF TRANSPORTATION

TECHNOLOGY ADVANCEMENT

August 2004

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
RED-08-02		

4. Title and Subtitle	5. Report Date
Report on Early Distress (RED) Investigation of PCC Pavement on STH 29	Aug-04
	6. Performing Organization Code WisDOT Highway Research Study RED-01-04
7. Author(s) Joe Wilson, Wisconsin Department of Transportation	8. Performing Organization Report No. RED-08-02
9. Performing Organization Name and Address Wisconsin Department of Transportation DTID/BHC/Pavements Section/Technology Advancement Unit 3502 Kinsman Blvd. Truax Center Madison, WI. 53704-2507	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Wisconsin Department of Transportation DTID/BHC/Pavements Section/Technology Advancement Unit 3502 Kinsman Blvd. Truax Center Madison, WI. 53704-2507	13. Type of Report and Period Covered Final Report 1999-2003 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A Report of Early Distress (RED) for STH 29 in eastern Shawano County was received from WisDOT District 3 Staff in August of 2000. They were concerned that a concrete paving project (10 inch, doweled PCC) constructed in 1999 was showing early distress almost immediately after construction. Problems arose in the form of deteriorated concrete, delaminated areas, punch downs and top-down deterioration of the concrete. Numerous clay-filled holes were also evident in the pavement's surface along with various areas that exhibited a brownish tint on the pavement surface. The edge of the concrete was deteriorated in various places as well. WisDOT extracted a total of 37 six-inch cores from the pavement in an effort to determine the cause of the early distress. Cores were tested for compressive strength, freeze/thaw durability and overall quality. Petrographic analyses were performed by two separate laboratories. The major recommendation stressed the importance of ensuring that every effort is made to ensure that the materials incorporated into a project meet the specifications so as to avoid poor pavement performance

17. Key Words	18. Distribution Statement
Delamination, PCC, Clay lumps, sand layers, poor mixing, freeze/thaw durability, contaminated aggregate, petrographic analysis	Distribution unlimited Report authorized for public release

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
unclassified	unclassified	54	

REPORT ON EARLY DISTRESS (RED)

Investigation of PCC Pavement on STH 29

FINAL REPORT # RED-08-02

WisDOT Highway Research Study # RED 01-04

By

Joe Wilson
Technology Advancement Specialist

For

WISCONSIN DEPARTMENT OF TRANSPORTATION
DIVISION OF TRANSPORTATION INFRASTRUCTURE DEVELOPMENT
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AUGUST 2004

TABLE OF CONTENTS

INTRODUCTION

A Report of Early Distress (RED) for STH 29 in eastern Shawano County was received from Anthony Allard, WisDOT District 3 Pavement Engineer in August of 2000. WisDOT District 3 staff were concerned that a concrete paving project constructed in 1999 was showing early distress almost immediately after construction. This resulted in an investigation to determine the causes and reasons for the early distress. This report describes the findings of that investigation along with recommendations to address the problem(s).

PROJECT OVERVIEW / BACKGROUND INFORMATION

Highway	: STH 29 East & West, Shawano County
Project ID	: 1059-16-80 & 1059-16-81
Project Location	: CTH J – CTH D (North) & CTH D (North) – Mill Creek
Date Constructed	: 1999

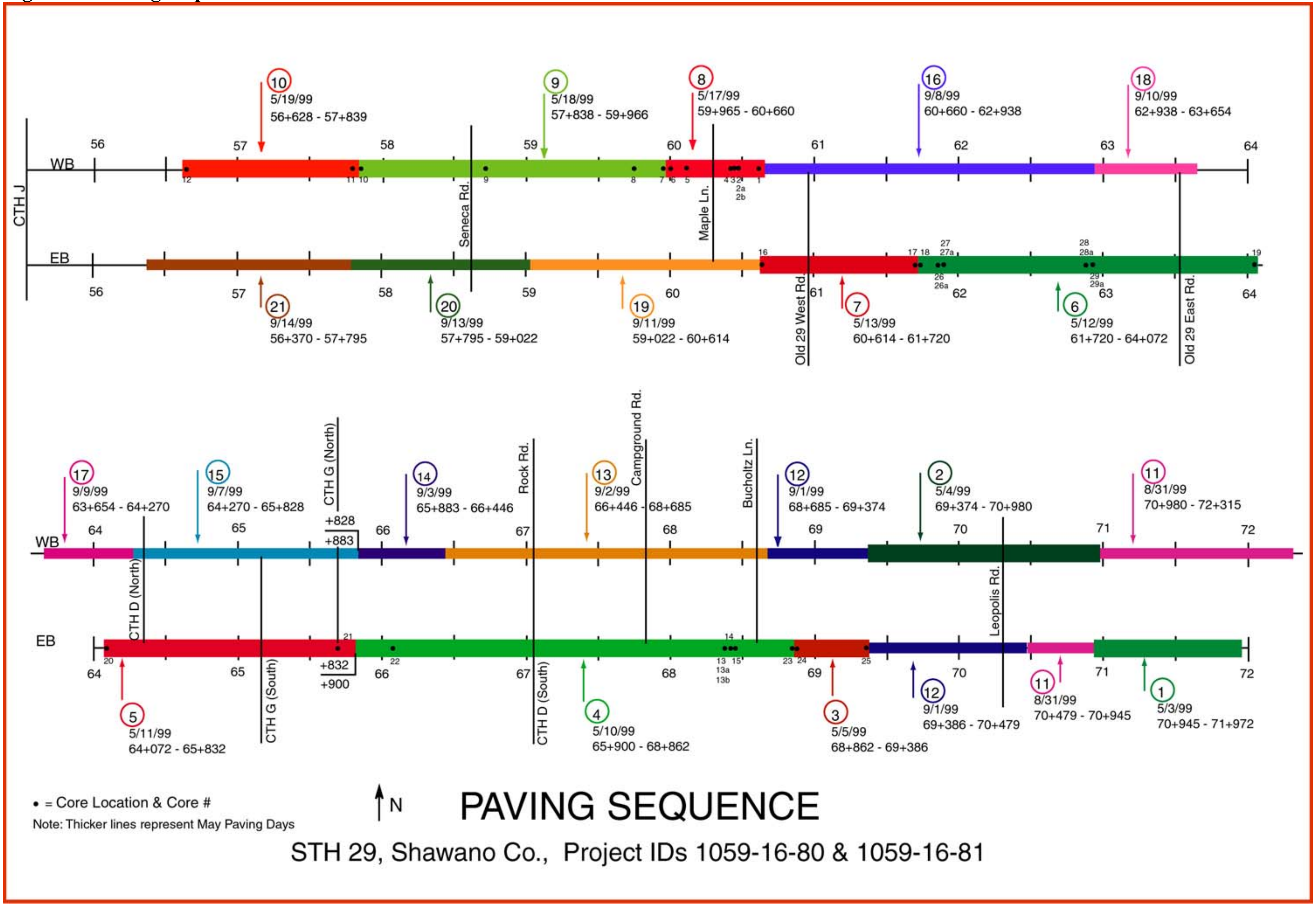
Distress Description

As stated above, this project, a 10-inch, doweled, PCC pavement was constructed in 1999 and problems arose immediately thereafter in the form of deteriorated concrete, delaminated areas, punch downs and top-down deterioration of the concrete. Numerous clay-filled holes were evident in the pavement's surface, along with various areas that exhibited a brownish tint on the pavement surface. The edge of the concrete pavement was deteriorated in various places as well. Appendix B on page 15 contains photographs of the pavement in question.

Paving Sequence

The pavement in question consisted of two separate projects that were constructed as one project, i.e. parts of one project were paved prior to completion of the other project and vs. versa. This is noted because the pavement in question relates to those sections that were paved in May (as opposed to the sections that were paved later that year in August and September). Figure 1 on the following page contains a map of the project illustrating the paving sequence and locations where cores were extracted from the pavement.

Figure 1. Paving Sequence



DATA COLLECTION

Due to early concerns with questionable pavement, the contractor extracted four cores from the pavement in October of 1999 for independent testing. Three of the four cores showed problems with distinct sand pockets or layers, while the other core appeared to be solid (See Appendix D on page 36). These cores were extracted from two different sections in the westbound lane that were paved 5/17/1999 and 5/18/1999 (paving days 8 and 9 respectively). In November 1999 the contractor repaired several spalled areas requiring attention – only six months after construction. WisDOT was not provided the results of the independent testing performed on the extracted cores.

Crack Survey

On August 11, 2000, District 4 Project Engineer Doug Ross performed a distress survey for the pavement placed during the 10 paving days in May of 1999. Seven of the ten paving days had mid-panel cracks, spalls, and/or patches placed to fix distressed areas needing immediate repair. The pavement placed on May 12, 1999 (paving sequence number 6) had 41 transverse cracks over 1.46 miles. This averaged out to one crack every 188 feet. The complete crack survey can be found in Appendix C on page 31.

Pavement Coring

For this investigation, three different sets of cores (37 total) were extracted (by WisDOT) from various locations that were paved in May. The following is written in chronological order as events unfolded. All data collection efforts and test results will be summarized near the end of this report prior to the conclusions and recommendations. This is mentioned because as one reads through the report, it may become confusing with all the different testing that was performed.

On July 12, 2001 WisDOT extracted 15 six-inch cores in an effort to gage the quality of the concrete that was placed on this project. Two of the cores were sent to American Petrographic Services, Inc. in St. Paul, Minnesota for petrographic analysis, while the remaining 13 cores were photographed and tested for compressive strength at WisDOT's Materials and Testing Laboratory.

Compressive Strength Testing

Overall, the results show the compressive strength was adequate for the cores that were tested, however those results were quite variable, ranging from 3670 psi to 8310 psi. Table 1 below contains the compressive strength test results along with the day the pavement was placed and the paving sequence number. Core #'s 2 and 13 were set aside for petrographic analysis.

Table 1 Compressive Strength Test Results

Core #	1	3	4	5	6	7	8	9	10	11	12	14	15
PSI	3670	5120	5680	7920	6160	8310	7100	6960	7000	7511	4080	4380	4380
Pav Seq	8	8	8	8	8	9	9	9	9	10	10	4	4
Day	5/17	5/17	5/17	5/17	5/17	5/18	5/18	5/18	5/18	5/19	5/19	5/10	5/10

Petrographic Analysis

The two cores sent to American Petrographic Services, Inc. were core # 13 placed 5/10/1999 on the 4th paving day and core # 2 placed 5/17/1999 on the 8th paving day. Laboratory testing on these two cores was performed on August 28, 2001 and subsequent dates. Based on their (American Petrographic Services, Inc.) observations, test results and past experiences, their main conclusions were as follows:

1. "The overall quality of the concrete was poor. The cement paste was highly variable in hardness from medium to very soft with carbonation up to 9/32 of an inch. The glacial gravel aggregate was hard, sound, and durable. The concrete was placed with a moderate to high slump."
2. "The concrete contained an air void system that is consistent with current technology for resistance to freeze-thaw deterioration. However, we expect deterioration to occur in the highly porous paste areas if exposed to freezing conditions when saturated."
3. "The concrete in each core is a layered mixture of two, very different concretes. The concrete was very poorly mixed and may represent two separate loads, with alternating zones of low and very high water to cement ratio."

Ground Penetrating Radar (GPR) Profiling

At the same time the initial 15 pavement cores were being extracted, WisDOT collected a series of GPR profiles in the immediate vicinity of the core locations. The purpose of this profiling was to obtain additional information on the structural problems observed in the pavement. A Mala Geoscience RAMAC GPR unit with an 800 MHz antenna was used to obtain the profiles.

The GPR unit was programmed to collect readings every 5 cm along the survey lines with the data instantaneously displayed and stored on a notebook PC. The data was later processed and interpreted using the Interpex GRADIX® software package.

The GPR data was obtained by collecting 3 profiles down the driving lane parallel to the centerline with one of the profiles intersecting each core location. Two of the profiles were run in the left and right wheel paths, while the third transect was run down the center of the lane between the wheel paths. In areas where the cores were isolated, the GPR profiles covered the two slabs immediately adjacent to the core location as well as the slab the core was extracted from. Where multiple cores were taken in relatively short distances, the GPR profiles were run to include the entire distance between the slabs the cores were taken from as well as the two slabs on either end of those slabs.

The results of the GPR profiling were inconclusive with respect to the structural integrity of the pavement. Pavement slab thickness and details within the shallow (near surface) subgrade were readily apparent. However, GPR signal resolution within the pavement slab itself was poor due primarily to the antenna frequency utilized. A 1 GHz or higher antenna frequency would provide better resolution of structural details within the pavement slab. WisDOT does not currently own an antenna with a frequency higher than 800 MHz so this antenna was used in an attempt to obtain additional data on the pavement slab. It is noted here for informational purposes that WisDOT is currently in the process of acquiring an antenna capable of "looking into" the pavement structure for this type of application in the future.

Additional Coring / Testing

During the course of the investigation, the section of pavement that initiated the RED report was expanded in scope due to heightened concerns about pavement placed in the same time frame. As a result, on October 18, 2001, an additional 10 six-inch cores (core #'s 16-25) were extracted in an effort to further define the areas of suspect pavement quality. The cores were photographed in both a dry and wet state and subjected to freeze/thaw durability testing. While several of the cores exhibited visual evidence of being poorly mixed, only one of them failed the freeze/thaw durability test. That was core number 16, which was placed on 5/13/1999, the 7th paving day.

The third and final set of 12 cores was extracted on November 8, 2001. The purpose of the last set of cores was to further define (again) the limits of suspect concrete (through freeze/thaw durability testing), as well as to cross-validate the initial petrographic analysis. Freeze/thaw durability tests were run on ten of the cores, while the remaining two cores were sent to the FHWA Turner-Fairbank Highway Research Center in McLean, Va. for the petrographic analysis.

Five of the ten cores (2A, 26, 26A, 27, 27A) from the final coring set failed the freeze/thaw durability test while a sixth core (29A) was borderline in terms of pass/fail. The cores corresponded to paving on May 12th and May 17th, paving days 6 and 8 respectively. Three of the cores (2A, 26, 26A) actually fell apart and split through sand layers in the cores during the test. Table 2 on the following page, contains the freeze/thaw durability test results for the last set of cores that were tested. Freeze/thaw testing for durability was performed as per Method A of ASTM C666. As a frame of reference, good quality concrete typically experiences about 2% section loss when subjected to the freeze/thaw durability test after 300 cycles. Pictures of the concrete specimens subjected to the freeze/thaw durability test can be found at the end of Appendix B.

Table 2 STH 29 Freeze/Thaw Durability Test Results
STARTED TEST: 12/05/2001
ENDED TEST: 1/30/2002

Cycles:	37	71	106	147	197	302	
	%LOSS	%LOSS	%LOSS	%LOSS	%LOSS	%LOSS	
Core #							
2A	1	3	3	11	18	22	split thru sand layer
13A	0	1	1	1	1	1	
26	0	0	1	6	7	9	split thru sand layer
26A	4	7	10	16	24	29	split thru sand layer
27	2	3	4	4	6	10	
27A	2	3	3	4	5	6	
28	0	0	0	0	0	0	
28A	0	0	0	0	0	0	
29	0	1	1	1	1	2	
29A	1	1	2	2	2	3	

Photos of these concrete specimens can be found at end of Appendix B.

Cross-Validation of Initial Petrographic Analysis

As stated above, two cores from the last coring operation were sent to the FHWA Turner-Fairbank Highway Research Center in McLean, Va. in an effort to cross-validate the initial petrographic analysis performed by American Petrographic Services, Inc. of St. Paul, Mn. Thus, these two cores were extracted adjacent to where the initial petrographic analysis was performed. These two cores were labeled as 2B and 13B. The findings from the second petrographic analysis did indeed corroborate the initial analysis and are as follows (See Appendix F on page 40 for the complete report, photos of the cores are found at the end of Appendix F):

- "Regions of dark-colored paste were found in the polished sections, and paste appeared dense and moderately strong in these regions. In some portions of the concrete, the cement paste was weaker, softer, more porous, and lighter in color, in contrast to concrete of high quality. A weak layer was found in core 13B. In this layer, the cement content was so inadequate that sand particles were poorly bonded."

- "Deterioration was found in the concrete samples, with the presence of microcracks in cement paste and aggregate. Although microcracks were found from both the top and bottom portions of the core, they were most prevalent in the top portion of the concrete core. Some cracks originated from the aggregate-cement paste interface and extended into the paste. Some cracks formed networks in the paste. In some cases cracks extend through air voids."
- "The average air content in the concrete was 3.0%. The spacing factor was 0.019 in., which is greater than the ACI recommended maximum spacing factor of 0.008 in. for freezing-thawing durable concrete."
- "Carbonation occurred mainly in the near-surface zone of the concrete, but in some portions, the carbonation extended as deep as ½ in. into the concrete."
- "Unhydrated cement particles were present in both samples."
- "Findings indicated that there was ettringite crystal as secondary deposits formed in the concrete. The distribution of ettringite was not even along the core. Voids in the top portion were more frequently filled with ettringite than voids in the bottom portion of the core. Generally, ettringite was found only partially filling in or lining the voids."

Project Records Check

The project records were checked in an attempt to find anything out of the ordinary that happened during construction. Two deficiency reports were found that indicated that the P200 percentage of the fine aggregate was out of specification for the concrete mix. The dates of these reports were Friday May 7th, and Monday May 10th.

SUMMARY

Aside from the 4 cores that were extracted by the contractor (3 of which exhibited distinct sand layers or pockets), WisDOT extracted a total of 37 six-inch cores from those pavement sections placed in May of 1999. Of the 37 cores, petrographic analyses were performed on 4 of the cores (all 4 had problems), compressive strength testing was performed on 13 of the cores (adequate strength, but quite variable) and freeze/thaw durability testing was performed on the remaining 20 cores (7 failed/were questionable). The cores with questionable freeze/thaw durability results related to those days paved on May 10th, 12th, 13th and 17th, paving days 4, 6, 7 and 8. Prior to testing, the cores were photographed in both a dry and a wet state for documentational purposes. Two separate petrographic analyses performed by different laboratories found significant problems with the quality of the concrete. The four cores that were analyzed were from pavement sections that were placed on May 10th (4th paving day) and May 17th (8th paving day).

Visual surface distress as described in the beginning of this report is evidence of poor concrete quality for the days paved in May being proposed for replacement without freeze/thaw or petrographic evidence (see Table 3 below). In fact, a June, 2002 field survey found that the brownish tint to the pavement surface noticed in various areas was a precursor to more serious deterioration of the pavement (see photos 17-18 in Appendix B on page 24).

Table 3 Paving/Coring/Testing Summary

Paving Day / Dir	Paving Date	Stationing (Metric) From	Stationing (Metric) To	Distance Paved (ft.)	8/11/2000 Crack Survey	Pavement Core Information: Total Taken	Tested for F/T Dur.	Failed F/T Dur.	Petrographic Analysis	Failed Petrographic
1 EB	5/3/99	70 + 945	71 + 972	3369	0	0	0	0	0	0
2 WB	5/4/99	69 + 374	70 + 980	5268	0	0	0	0	0	0
3 EB	5/5/99	68 + 862	69 + 386	1719	0	2	2	0	0	0
4 EB	5/10/99	65 + 900	68 + 862	9715	4C, 3P, 1S	7*	3	0	2	2
5 EB	5/11/99	64 + 072	65 + 832	5773	11C	2	2	0	0	0
6 EB	5/12/99	61 + 720	64 + 072	7715	41C	10	10	5	0	0
7 EB	5/13/99	60 + 614	61 + 720	3628	12C, 1S	2	2	1	0	0
8 WB	5/17/99	59 + 965	60 + 660	2280	10C, 5P	8*	1	1	2	2
9 WB	5/18/99	57 + 838	59 + 966	6980	28C, 2P	4**	0	0	0	0
10 WB	5/19/99	56 + 628	57 + 839	3972	5C, 1S	2**	0	0	0	0

* = remaining cores were tested for compressive strength
** = all cores tested for compressive strength

Distress Codes:
C = Crack
P = Patch
S = Spall

(grey) =DOT's Replacement Proposal
(yellow) =Contractor's Replacement Proposal

CONCLUSIONS

1. This project, a 10-inch, doweled, PCC pavement was constructed in 1999 and problems arose immediately thereafter in the form of deteriorated concrete, delaminated areas, punch downs and top-down deterioration of the concrete. Numerous clay-filled holes were evident in the pavement's surface, along with various areas that exhibited a brownish tint on the pavement surface. The edge of the concrete pavement was deteriorated in various places as well.
2. The primary cause of the early distress appears to be poor mixing of the concrete, evidenced by layers or pockets of sand with low cement content.
3. Clay pockets or globules in the pavement didn't help the mixing and are likely a result of scraping the bottom of the aggregate pile.
4. Overall, the results show the compressive strength was adequate for the initial set of cores that were tested, however the results of the compressive strength testing were quite variable, ranging from 3670 psi to 8310 psi.
5. Seven of the ten paving days had mid-panel cracks, spalls, and/or patches placed to fix distressed areas needing immediate repair. The pavement placed on May 12, 1999 (paving sequence number 6) had 41 transverse cracks over 1.46 miles.
6. Two deficiency reports were found that indicated that the P200 percentage of the fine aggregate was out of specification for the concrete mix. The dates of these reports were Friday May 7th and Monday May 10th.
7. Petrographic analysis performed on core #'s 13 and 2 (placed 5/10/1999 and 5/17/1999 respectively) by American Petrographic Services Inc. provided the following main conclusions:
   a. "The overall quality of the concrete was poor. The cement paste was highly variable in hardness from medium to very soft with carbonation up to 9/32 of an inch. The glacial gravel aggregate was hard, sound, and durable. The concrete was placed with a moderate to high slump."
   b. "The concrete contained an air void system that is consistent with current technology for resistance to freeze/thaw deterioration. However, we expect deterioration to occur in the highly porous paste areas if exposed to freezing conditions when saturated."

   c. "The concrete in each core is a layered mixture of two, very different concretes. The concrete was very poorly mixed and may represent two separate loads, with alternating zones of low and very high water to cement ratio."

8. Petrographic analysis performed on companion cores 13b and 2b by FHWA's Turner-Fairbank Highway Research Center (TFHRC) provided the following results:
   a. "Regions of dark-colored paste were found in the polished sections, and paste appeared dense and moderately strong in these regions. In some portions of the concrete, the cement paste was weaker, softer, more porous, and lighter in color, in contrast to concrete of high quality. A weak layer was found in core 13B. In this layer, the cement content was so inadequate that sand particles were poorly bonded."
   b. "Deterioration was found in the concrete samples, with the presence of microcracks in cement paste and aggregate. Although microcracks were found from both the top and bottom portions of the core, they were most prevalent in the top portion of the concrete core. Some cracks originated from the aggregate-cement paste interface and extended into the paste. Some cracks formed networks in the paste. In some cases cracks extend through air voids."
   c. "The average air content in the concrete was 3.0%. The spacing factor was 0.019 in., which is greater than the ACI recommended maximum spacing factor of 0.008 in. for freezing-thawing durable concrete."
   d. "Carbonation occurred mainly in the near-surface zone of the concrete, but in some portions, the carbonation extended as deep as ½ in. into the concrete."
   e. "Unhydrated cement particles were present in both samples."
   f. "Findings indicated that there was ettringite crystal as secondary deposits formed in the concrete. The distribution of ettringite was not even along the core. Voids in the top portion were more frequently filled with ettringite than voids in the bottom portion of the core. Generally, ettringite was found only partially filling in or lining the voids."
9. The results of the GPR profiling were inconclusive regarding the structural integrity of the pavement. Pavement slab thickness and details within the shallow subgrade were

readily apparent. However, GPR signal resolution within the pavement slab itself was poor due primarily to the antenna frequency utilized.

10. Pavement thickness was adequate and did not contribute to any distress.

RECOMMENDATIONS

1. The major recommendation here is to stress the importance that every effort is made to ensure that the materials incorporated into a project meet the specifications so as to avoid poor pavement performance.
2. It is also recommended that the Concrete Pavement Technical Committee consider reviewing and updating the P200 sieve specification to tighten the specification. It appears that the contractor was operating "on the edge" of the specification and, due to the frequency of random sampling, may have been in and out of the specification on the days in question with respect to the P200 percentage of the fine aggregate in the concrete mix. It is important to re-emphasize that the testing requirements listed in the specifications represent minimum frequencies, and more testing should be conducted if a material source is "on the edge" of the specification.

APPENDIX A

(Original RED Report)

REPORT ON EARLY DISTRESS (RED) IN HIGHWAYS AND BRIDGES

1. Location of Apparent Distress:

Highway: STH 29 E W S N Date Constructed: 1999
Project ID: 1059-16-80 & 1059-16-81 City / Village: - - -
Bridge ID: - - - County: Shawano
Project Begin / End: CTH J-CTH D (North) & CTH D (North)-Mill Creek

Other Location Info: (Distance, Direction, Reference Point, Intersection, Landmark, etc.)

STH 29 Team Project managed by Mike Paddock of CH2M Hill
Westbound Total ~ 2.5 miles
Start 1.75 miles West of Old STH 29 East (STATION +/- 60+700)
End 4.25 miles West of Old STH 29 East (STATION +/- 56+700)

The following location is also showing signs of distress:

Eastbound Total ~ 0.3 miles
Start 2.90 miles East of Old STH 29 East (STATION +/- 68+200)
End 3.20 miles East of Old STH 29 East (STATION +/- 68+700)

2. Highway / Bridge Element where Distress Appears: (x)

Highway: X Pavement ___Shoulder ___Embankment ___Drainage

___Marking/Signing ___Hardware

Bridge: ___Deck ___Railing ___Expansion Joint ___Substructure ___Other

Explanation: Deteriorating Concrete

3. Probable Cause of Distress: Lack of cement or improper mixing

4. Recommended Action / Correction (How would you handle it?): Replacement

5. Report Submitted by: Anthony Allard Telephone #: (920) 492-3510
Bureau, Section, Unit: Highways, Pavement, Technical Services
2 nd Name, Unit & Phone: Al Rommel, Technical Services, (920) 492-5675
District: 1 2 3 4 5 6 7 8 CO (Underline One) Date Submitted: 08-02-00

Send Report To: Technology Advancement Unit, Bureau of Highway Construction
Attention: Joe Wilson, Technology Advancement Specialist
3502 Kinsman Blvd.
Truax Center
Madison, WI. 53704-2507
Or email to: joe.wilson@dot.state.wi.us

APPENDIX B

(Photographs)

Print 1. Example of the numerous unmixed clay deposits.

Print 2. Another view of a pocket of clay.

Print 3. A partial depth repair of a delaminated section. A brownish discoloration of the PCC is evident.

Print 4. A punch-down caused by poor mixing and resulting voids.

Print 5. Notice the brownish discoloration of the PCC pavement in this area of repairs.

Print 6. Again, notice the brownish discoloration of the PCC pavement in this area of repairs.

Print 7. The pavement here is deteriorating from the top down.

Print 8. The locations of the dowel bars are visible from the surface.

Print 9. A close-up view of poorly mixed concrete.

Print 10. A view of a type of early distress for this pavement based on poor mixing.

Print 11. Another view of the "typical" early distress occurring on this project.

Print 12. Notice how the clay deposit is sticking to the end of the pen and the void in the pavement.

Print 13. Example of a mid-panel crack.

Print 14. Notice the brownish tint to the pavement in the vicinity of the patch.

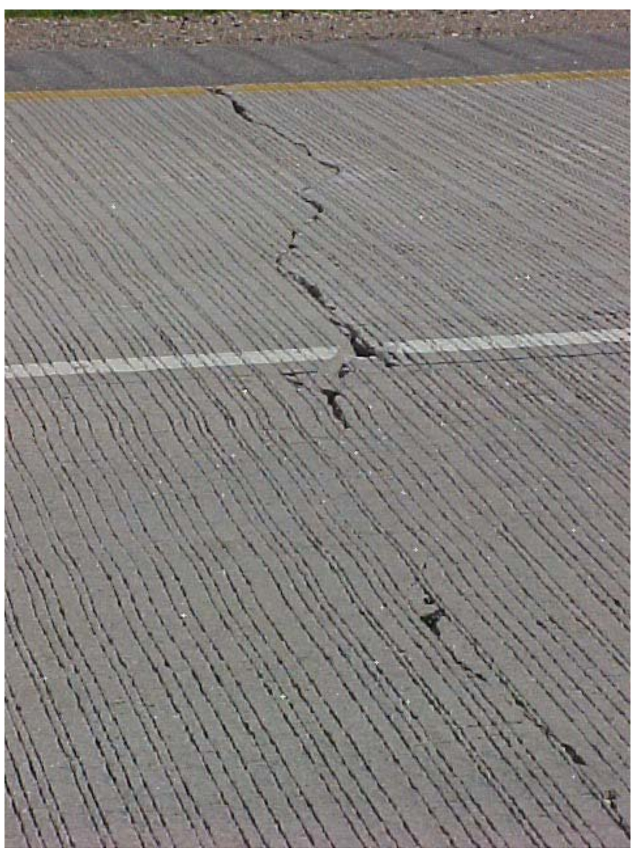
Print 15. View of the raveled edge distress prevalent on the project.

Print 16. Example of the sand layering found throughout the project. Water from the coring operation disintegrated the sandy layer at mid-core depth as shown above.

Print 17. Example of a patch, photo taken 6-15-00. Patch is located at station 68+383 EB.

Print 18. A view of the same patch above, taken 11-8-01, a little more than 1 year after above photo.

Print 19. Photo taken June 2002.



Print 20. Photo taken June 2002.

Print 21. View of a slab cross-section that was replaced in August 2002.

Print 22. Another slab that was replace in August 2002.

Print 23. Again, a look at a slab being replaced August 2002.

Print 24. Another slab that was replaced in August 2002. Notice the sand layer.

Print 25. Another slab with the distinct sand layer, this was replaced in August 2002.

Print 26. The sand layer, in this case, runs near the bottom and mid-portion of the slab.

Print 27. Another view of the previous photo.

Print 28. View of a slab being removed for replacement (August 2002).

Prints 29-36. Freeze-thaw durability test results after 302 lab freeze-thaw cycles.

APPENDIX C
(Crack Survey)

STH 29 Report on Early Distress (RED)
CTH J to Mill Creek, Shawano County
Date Constructed: May, 1999;   Crack Survey: August 11, 2000

Station (Metric)	Location East or West	Description	Spacing (feet)
60 + 622.35	Eastbound	Header End Paving 5/13/99	
60 + 815.40	Eastbound	Spall	633
60 + 861.65	Eastbound	Crack	152
60 + 893.83	Eastbound	Crack	106
60 + 960.17		Old 29 West (60 + 960.17)	
61 + 026.86	Eastbound	Crack	436
61 + 069.31	Eastbound	Crack	139
61 + 103.66	Eastbound	Crack	113
61 + 168.34	Eastbound	Crack	212
61 + 173.39	Eastbound	Crack	17
61 + 207.75	Eastbound	Crack	113
61 + 351.25	Eastbound	Crack	471
61 + 380.55	Eastbound	Crack	96
61 + 563.46	Eastbound	Crack	600
61 + 655.42	Eastbound	Crack	302
61 + 723.12	Eastbound	Header Begin Paving 5/13/99	
61 + 758.49	Eastbound	Crack	116
61 + 784.77	Eastbound	Crack	86
61 + 808.01	Eastbound	Crack	76
61 + 824.18	Eastbound	Crack	53
61 + 862.58	Eastbound	Crack	126
61 + 878.75	Eastbound	Crack	53
61 + 885.82	Eastbound	Crack	23
61 + 923.21	Eastbound	Crack	123
61 + 939.38	Eastbound	Crack	53
61 + 984.85	Eastbound	Crack	149
62 + 023.26	Eastbound	Crack	126
62 + 077.82	Eastbound	Crack	179
62 + 116.22	Eastbound	Crack	126
62 + 149.57	Eastbound	Crack	109
62 + 206.16	Eastbound	Crack	186
62 + 222.33	Eastbound	Crack	53
62 + 292.06	Eastbound	Crack	229
62 + 336.52	Eastbound	Crack	146
62 + 389.07	Eastbound	Crack	172
62 + 411.30	Eastbound	Crack	73
62 + 448.69	Eastbound	Crack	123
62 + 499.22	Eastbound	Crack	166
62 + 510.34	Eastbound	Crack	36
62 + 615.43	Eastbound	Crack	345
62 + 759.94	Eastbound	Crack	474
62 + 799.35	Eastbound	Crack	129
62 + 816.53	Eastbound	Crack	56

62 + 899.39	Eastbound	Crack	272
63 + 108.58	Eastbound	Crack	686

STH 29 Report on Early Distress (RED)
CTH J to Mill Creek, Shawano County
Date Constructed: May, 1999; Crack Survey: August 11, 2000

Station (Metric)	Location East or West	Description	Spacing (feet)
63 + 229.84	Eastbound	Crack	398
63 + 285.42	Eastbound	Crack	182
63 + 307.65	Eastbound	Crack	73
63 + 339.99	Eastbound	Crack	106
63 + 421.84	Eastbound	Crack	268
63 + 489.55	Eastbound	Crack	222
63 + 516.83	Eastbound	Crack	89
63 + 539.07		Old 29 East (63 + 539.07)	
63 + 642.87	Eastbound	Crack	413
63 + 717.45	Eastbound	Crack	245
63 + 759.78	Eastbound	Crack	139
63 + 793.04	Eastbound	Crack	109
63 + 839.41	Eastbound	Crack	152
64 + 071.22	Eastbound	Header Begin Paving 5/12/99	
64 + 092.39	Eastbound	Crack	69
64 + 302.03	Eastbound	Crack	688
64 + 349.40		CTH D North (64 + 349.40)	
64 + 369.59	Eastbound	Crack	222
64 + 514.87	Eastbound	Crack	477
64 + 561.28	Eastbound	Crack	152
64 + 845.79	Eastbound	Crack	933
64 + 993.09	Eastbound	Crack	483
65 + 074.81	Eastbound	Crack	268
65 + 132.32	Eastbound	Crack	189
65 + 168.64		CTH G South (65 + 168.63	
65 + 566.15	Eastbound	Crack	1420
65 + 691.25		CTH G North (65 + 693.00)	
65 + 704.05	Eastbound	Crack	452
65 + 850.72		N. Branch Embarrass River	
65 + 850.72	Eastbound	Begin Paving 5/11/99	
66 + 056.66	Eastbound	Patches	1157
66 + 438.40	Eastbound	Crack	1252
66 + 513.75	Eastbound	Crack	247
66 + 869.37	Eastbound	Spall	1166
67 + 051.20		CTH D South (67 + 051.242)	
67 + 841.68		Camp Ground Road (67 + 841.68)	
68 + 382.55	Eastbound	Patch	4963
68 + 447.05	Eastbound	Patch	212
68 + 632.48		Bucholtz Lane (68 + 632.59)	
68 + 861.25	Eastbound	Header Begin Paving 5/10/99	

69 + 386.31	Eastbound	Header Begin Paving 5/05/99	
69 + 374.00	Westbound	Header End Paving 5/04/99	
70 + 308.71		Leopolis Road (70 + 308.71)	
70 + 945.00	Eastbound	Header End Paving 5/03/99	
70 + 980.00	Westbound	Header Begin Paving 5/04/99	
71 + 972.00	Eastbound	Header Begin Paving 5/03/99	

STH 29 Report on Early Distress (RED)
CTH J to Mill Creek, Shawano County
Date Constructed: May, 1999; Crack Survey: August 11, 2000

Station (Metric)	Location East or West	Description	Spacing (feet)
55 + 634.95		CTH J (55 + 634.95)	
56 + 625.95	Westbound	Header End Paving 5/19/99	
56 + 735.27	Westbound	Spall	359
56 + 875.98	Westbound	Crack	462
57 + 272.78	Westbound	Crack	1302
57 + 322.38	Westbound	Crack	163
57 + 461.06	Westbound	Crack	455
57 + 555.20	Westbound	Crack	309
57 + 835.60	Westbound	Header Begin Paving 5/19/99	
57 + 899.37	Westbound	Crack	209
58 + 031.98	Westbound	Crack	435
58 + 150.41	Westbound	Crack	388
58 + 191.91	Westbound	Crack	136
58 + 330.59	Westbound	Crack	455
58 + 370.07	Westbound	Crack	129
58 + 382.22	Westbound	Crack	40
58 + 405.50	Westbound	Crack	76
58 + 456.11	Westbound	Crack	166
58 + 464.21	Westbound	Crack	27
58 + 544.18	Westbound	Crack	262
58 + 628.20		Seneca Road (58 + 628.20)	
58 + 773.98	Westbound	Crack	754
58 + 835.73	Westbound	Crack	203
58 + 968.35	Westbound	Crack	435
58 + 997.70	Westbound	Crack	96
59 + 016.94	Westbound	Crack	63
59 + 157.65	Westbound	Crack	462
59 + 279.13	Westbound	Crack	398
59 + 297.35	Westbound	Crack	60
59 + 341.89	Westbound	Crack	146
59 + 353.03	Westbound	Crack	37
59 + 403.65	Westbound	Crack	166
59 + 493.74	Westbound	Crack	295
59 + 522.09	Westbound	Crack	93
59 + 577.77	Westbound	Crack	183
59 + 665.84	Westbound	Crack	289
59 + 725.57	Westbound	Crack	196

59 + 754.93	Westbound	Crack and Patch	96
59 + 848.06	Westbound	Crack	305

STH 29 Report on Early Distress (RED)
CTH J to Mill Creek, Shawano County
Date Constructed: May, 1999; Crack Survey: August 11, 2000

Station (Metric)	Location East or West	Description	Spacing (feet)
59 + 965.49	Westbound	Header Begin Paving 5/18/99	
60 + 063.69	Westbound	Crack	322
60 + 105.19	Westbound	Patch	136
60 + 113.29	Westbound	Patch	27
60 + 118.35	Westbound	Crack	17
60 + 141.64	Westbound	Crack	76
60 + 159.86	Westbound	Patch	60
60 + 170.99	Westbound	Patch	37
60 + 179.09	Westbound	Crack and Patch	27
60 + 189.22	Westbound	Crack	33
60 + 228.70	Westbound	Crack	129
60 + 290.45	Westbound	Crack	203
60 + 302.60		Maple Lane (60 + 302.60)	
60 + 333.81	Westbound	Patch	142
60 + 420.42	Westbound	Patch	284
60 + 427.46	Westbound	Patch	23
60 + 444.58	Westbound	Crack	56
60 + 482.85	Westbound	Crack	126
60 + 661.09	Westbound	Header Begin Paving 5/17/99	585

APPENDIX D
(Sketch of Contractor Cores)

CH2Mhill Inc.

Memo

To: Dave Stertz / Wis DOT STH 29 team

From: Phil Santacroce / CH2Mhill

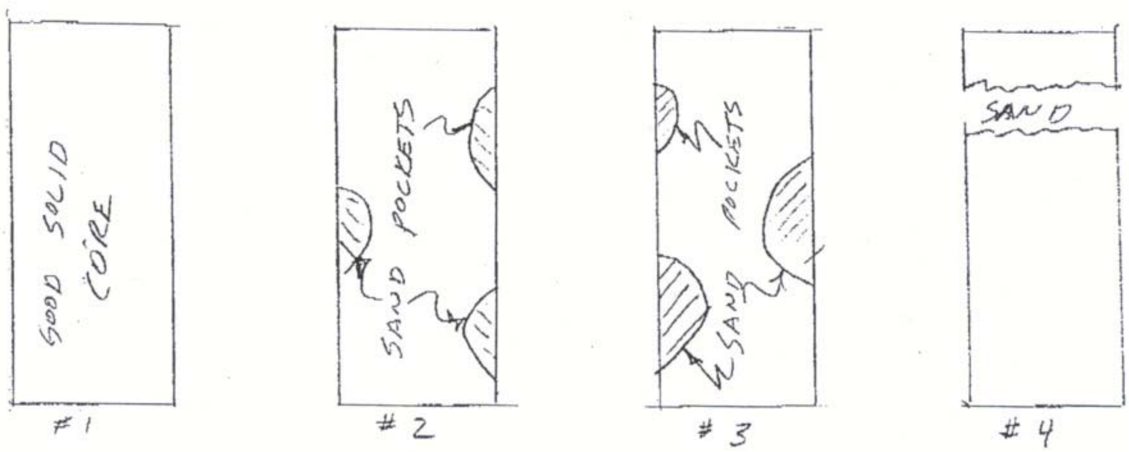
CC: Mike Paddock / CH2Mhill.
Joe Matchey /James Cape and Sons.
Frank Laufenberg / Hofman Construction Co.

Date: 12/07/99

Re: Defective Concrete Pavement

Dave:

This Memo is to confirm our previous conversations regarding the defective pavement in the WB Lane, from approximately Sta. 60+107 to Sta. 60+442 and also in the area of Sta. 59+741. The areas where defects are visible, have been repaired temporarily with Set 45. Next spring, after a winter of freeze thaw cycles the extent of the defects can be more fully assessed, then a course of action for permanent repairs will be made. Four cores were taken in the above area by Geo Test for Cape and sent to a testing lab. Below are four sketches of my observations of the cores at the time they were taken. Also attached is a letter from Frank Laufenberg for your information.



OPTIONAL FORM 99 (7-90)

FAX TRANSMITTAL	# of pages ► 1
To ANTHONY ALLARD	From RICHARD McCLAIN
Dept./Agency	Phone # 715-421-8387
Fax # 920-492-5640	Fax # 715-421-8076
NSN 7540-01-317-7368 5099-101	GENERAL SERVICES ADMINISTRATION

APPENDIX E
(Core Locations)

Core Number	Stationing (Metric)	Paving Day	Paving Date
11	57 + 800 WB	10	5/19/1999
12	56 + 650 WB	10	5/19/1999
7	59 + 960 WB	9	5/18/1999
8	59 + 750 WB	9	5/18/1999
9	58 + 723 WB	9	5/18/1999
10	57 + 850 WB	9	5/18/1999
1	60 + 603 WB	8	5/17/1999
2	60 + 443 WB	8	5/17/1999
2a	60 + 443 WB	8	5/17/1999
2b	60 + 443 WB	8	5/17/1999
3	60 + 427 WB	8	5/17/1999
4	60 + 419 WB	8	5/17/1999
5	60 + 116 WB	8	5/17/1999
6	60 + 001 WB	8	5/17/1999
16	60 + 625 EB	7	5/13/1999
17	61 + 708 EB	7	5/13/1999
18	61 + 734 EB	6	5/12/1999
19	64 + 050 EB	6	5/12/1999
26	61 + 859 EB	6	5/12/1999
26a	61 + 859 EB	6	5/12/1999
27	61 + 894 EB	6	5/12/1999
27a	61 + 894 EB	6	5/12/1999
28	62 + 895 EB	6	5/12/1999
28a	62 + 895 EB	6	5/12/1999
29	62 + 935 EB	6	5/12/1999
29a	62 + 935 EB	6	5/12/1999
20	64 + 087 EB	5	5/11/1999
21	65 + 700 EB	5	5/11/1999
22	66 + 080 EB	4	5/10/1999
23	68 + 850 EB	4	5/10/1999
13	68 + 378 EB	4	5/10/1999
13a	68 + 378 EB	4	5/10/1999
13b	68 + 378 EB	4	5/10/1999
14	68 + 417 EB	4	5/10/1999
15	68 + 445 EB	4	5/10/1999
24	68 + 875 EB	3	5/5/1999
25	69 + 371 EB	3	5/5/1999

Paving Day	Paving Date	Stationing (Metric) From	To	Distance Paved (ft.)	Dir
1	5/3/1999	70 + 945	71 + 972	3369	EB
2	5/4/1999	69 + 374	70 + 980	5268	WB
3	5/5/1999	68 + 862	69 + 386	1719	EB
4	5/10/1999	65 + 900	68 + 862	9715	EB
5	5/11/1999	64 + 072	65 + 832	5773	EB
6	5/12/1999	61 + 720	64 + 072	7715	EB
7	5/13/1999	60 + 614	61 + 720	3628	EB
8	5/17/1999	59 + 965	60 + 660	2280	WB
9	5/18/1999	57 + 838	59 + 966	6980	WB
10	5/19/1999	56 + 628	57 + 839	3972	WB

APPENDIX F
(Turner-Fairbank Highway Research Center
Petrographic Analysis)

Petrographic Examination of Concrete Cores from Wisconsin Department of Transportation

A report submitted to the Wisconsin Department of Transportation

Rongtang Liu, Ph.D.
Petrographic Laboratory
TFHRC

1. Abstract

Two concrete core samples (3.75-in. diameter and about 12 in. high) were received from the Wisconsin Department of Transportation on November 20, 2001, for petrographic examination. The two concrete cores (labeled as 2B and 13B, respectively) were retrieved from the pavement of a driving lane in a state highway. In the middle of core 13B was a weak layer (shown in Appendix), in which inadequate cementitious material with high porosity was observed. Petrographic examination was performed using polished concrete slabs, thin sections, and scanning electron microscope (SEM). Findings indicated that there was ettringite crystal as secondary deposits formed in the concrete. Deterioration was found in the concrete samples, with the presence of microcracks in cement paste and aggregate. Carbonation occurred mainly in the near-surface zone of the concrete, but in some portions, the carbonation extended as deep as ½ in. into the concrete.

2. Introduction

The Petrographic Laboratory staff of the Concrete Pavement Team, Turner-Fairbank Highway Research Center was asked by the Wisconsin Department of Transportation to evaluate a set of concrete cores retrieved from driving lane of a state highway. A color picture of the two cores was provided. Information about the structure of the pavement was provided, and some description of deterioration, observed from both pavement and cores, was given. Information about the exposure was not provided.

Specimen identifications provided by the Wisconsin Department of Transportation were used to serve as sample reference names.

3. Laboratory Procedures

Petrographic examination of the concrete samples was performed in accordance with ASTM C 856, “Standard Practice for Petrographic Examination of Hardened Concrete.” Sections were polished and examined using a stereomicroscope at magnifications up to 350×. Small rectangular blocks were cut from concrete samples. One surface of each block was polished, dried, placed on petrographic slide with low−viscosity epoxy resin, and reduced to a thickness of approximately 25 micrometers (0.001 in.). The thin sections were examined using a polarized−light microscope at magnification up to 400×, to determine aggregate mineralogy, paste characteristics, and microstructure.

Air void testing was performed in general accordance with ASTM C457-98, “Standard Test Method for Microscopical Determination of Parameters of the Air Void System in Hardened Concrete”, Procedure B−Modified Point-Count Method. Two ¾ inch thick sections, perpendicular to the surface, were cut form the concrete cores. They were polished and examined using a stereo microscope at a magnification of 100×.

Scanning Electron Microscopy provides detailed images of the concrete microstructure and performs chemical analysis. Small blocks with fresh fractured surface were taken from the concrete specimens for secondary electron image analysis.

4. Findings

Eight thin section samples taken from the concrete cores were examined under polarized light microscope) and five samples were examined under Scanning Electron Microscope (samples were from top, middle, and bottom of the cores). Two polished sections were examined under stereo microscope. The findings were summarized as follows:

Aggregate composition and morphology:
Coarse aggregates in the concrete samples were composed of granite, dolomite, basalt, gabbro, and quartzite. Coarse aggregate particles were angular to sub–rounded, and the maximum size was about 1–in. Preferential orientation was not observed.

The fine aggregate fraction was composed of quartz, with some dolomite, quartzite, and basalt. The fine aggregate particles ranged from rounded to angular.

Air void system in the hardened concrete:

The concrete was air-entrained (Figure 1) and the air void system parameters for the concrete cores are listed in Table 1. The average air content in the concrete was 3.0%. The spacing factor was 0.019 in., which is greater than the ACI recommended maximum spacing factor of 0.008 in for freezing-thawing durable concrete.

Paste and its microstructure:

Cement was reasonably hydrated. No significant difference was observed between different portions of the cores. Representative pictures were taken from thin sections of each core (Figures 2a and 2b). Unhydrated cement particles were present in both samples.

Air voids were well distributed in the paste and no significant difference along the core. The aggregate-paste interface appeared normal and consistent in different portions of the core.

Regions of dark-colored paste were found in the polished sections, and paste appeared dense and moderately strong in these regions. In some portions of the concrete, the cement paste was weaker, softer, more porous, and lighter in color, in contrast to concrete of high quality. A weak layer was found in core 13B. In this layer, the cement content was so inadequate that sand particles were poorly bonded.

Carbonation occurred in the cement paste. It mainly happened in the surface layer of the concrete, and the depth of carbonation varied in different regions. In some porous portions of cement paste or paste with cracks, the depth of carbonation extended as deep as ½ in. into the concrete.

Microcracks:

Microcracks were found in paste as well as in aggregate particles. Although microcracks were found from both the top and bottom portions of the core, they were most prevalent in the top portion of the concrete core. Some cracks originated from the aggregate-cement paste interface and extended into the paste (Figure 3). Some cracks formed networks in the paste (Figure 4). In some cases cracks extend through air voids (Figures 5 and 6).

Cracks in siliceous aggregate particles were observed in the concrete samples (Figures 7 and 8), although no significant damage to the concrete was observed in the tested samples. Some cracks were filled with gel-like material.

Secondary deposits:

Ettringite was found in these samples, as shown in Figures 9 and 10. The distribution of ettringite was not even along the core. Voids in the top portion were more frequently filled with ettringite than voids in the bottom portion of the core. Generally, ettringite was found only partially filling or lining in the voids.

Table 1. Parameters of the air void system in the concrete core samples.

Entrained Air, %	3.0
Paste, %	30.1
Fine Aggregate, %	27.3
Coarse Aggregate, %	39.6
Mean Chord Length, in.	0.0125
Voids per in.	2.5
Specific Surface, in^2/in^3	330
Spacing Factor, in.	0.019

5. Summary of Findings

The aggregate, paste, and aggregate-paste interface of the concrete cores appeared normal. A weak layer of low cement content was found in core 13B. In some portions of the concrete, the cement paste was softer, weaker, more porous, and lighter in color. Microcracks were observed in thin section samples and SEM samples. The measured air void system parameters were 3% air and 0.019 in. spacing factor. Ettringite crystals were found partially filling or lining air voids. The ettringite was found to be most prevalent near the surface, and in decreasing amounts with depth in the cores. No evidence of damage initiated by the formation of secondary ettringite was observed from these concrete cores.

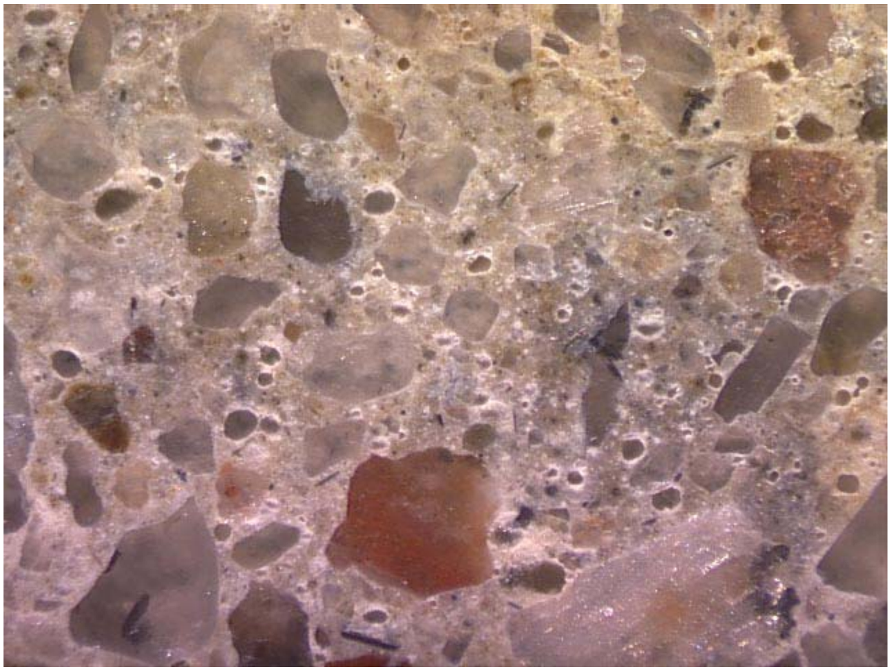


Figure 1. Concrete was air entrained. This picture was taken from a polished surface. Width of field 2.0mm.

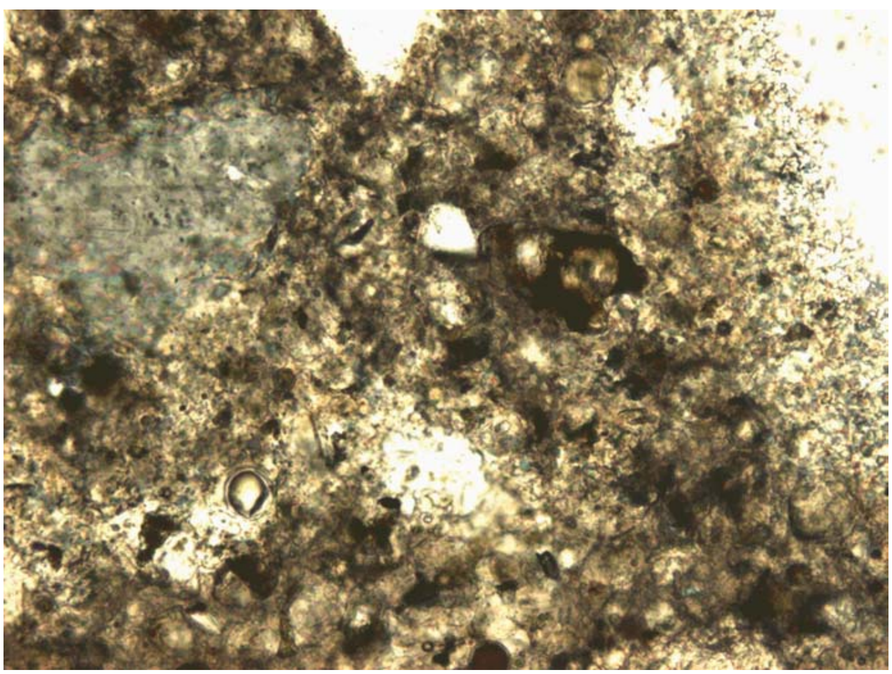


Figure 2a. Cement paste was reasonably hydrated, and unhydrated cement particles were present in the paste. This picture was taken from a thin section of core 2B. Width of field 0.33mm.

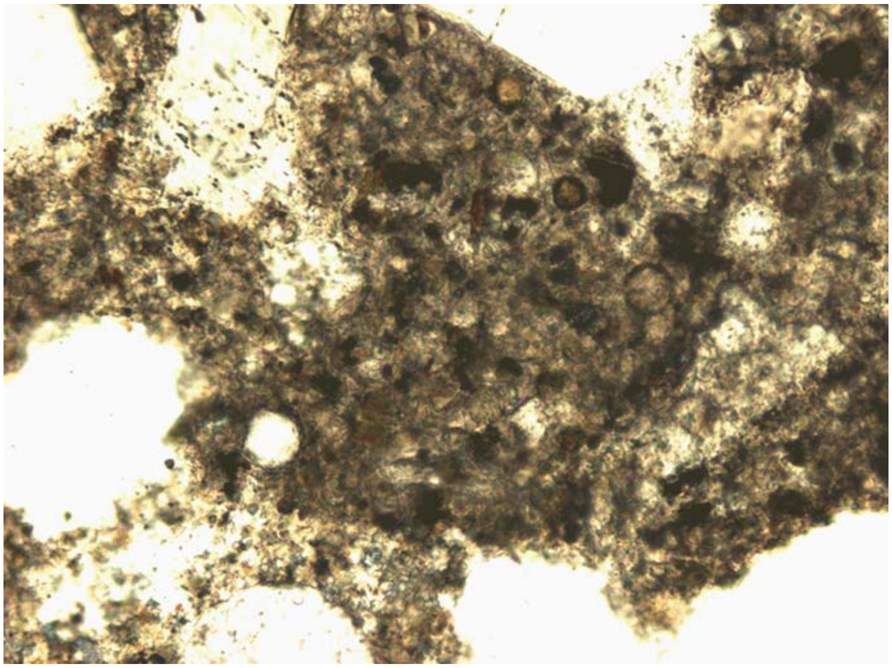


Figure 2b. Cement paste was reasonably hydrated, and unhydrated cement particles were present in the paste. This picture was taken from a thin section of core 13B. Width of field 0.33mm.

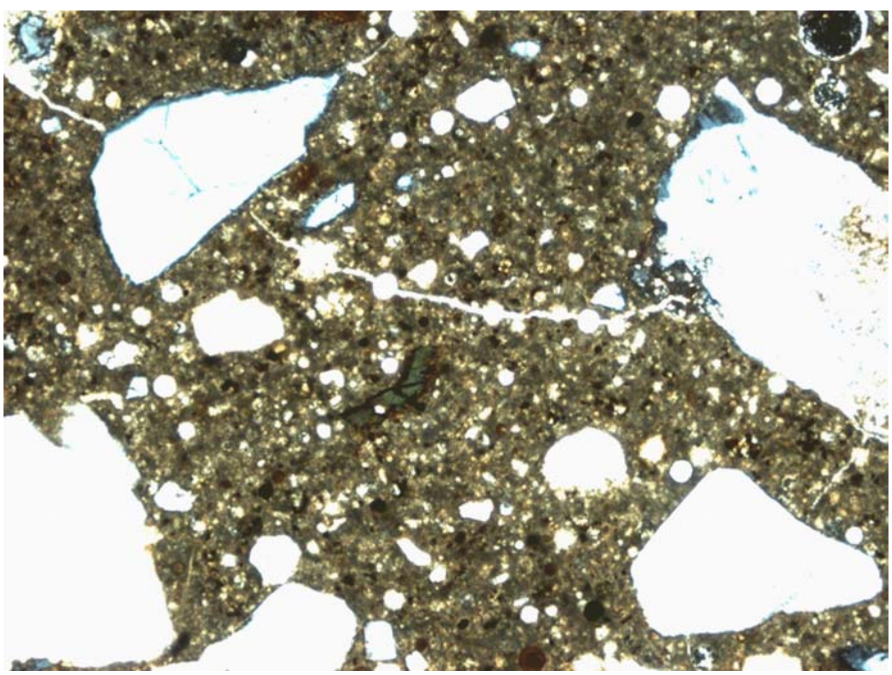


Figure 3. Microcracks in cement paste. This picture was from a thin section of the top portion of core 2B. Width of field 0.65mm.

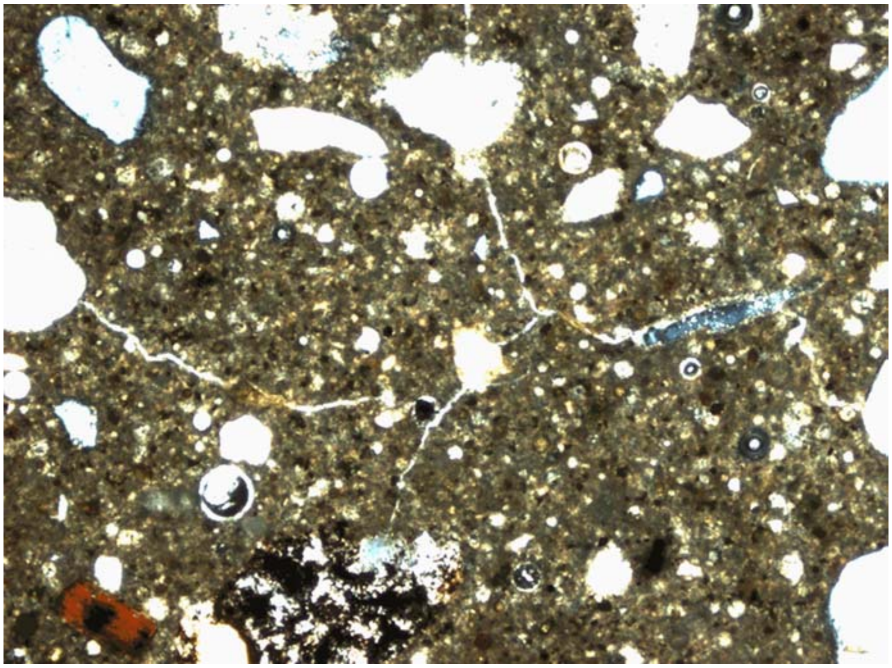


Figure 4. Cracking Network. This picture was taken from a thin section of the top portion of core 13B. Width of field 0.65mm.

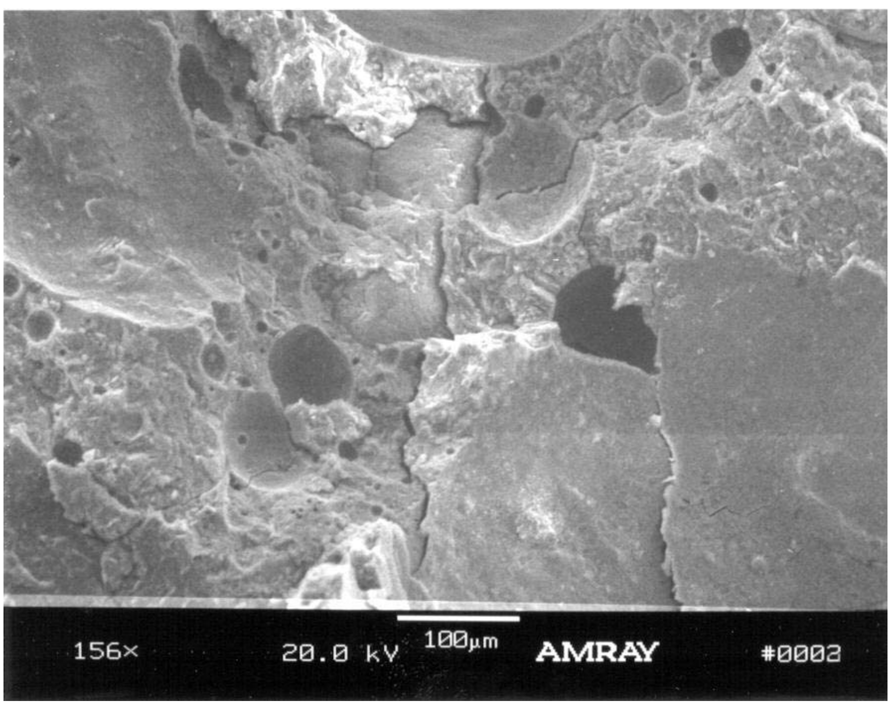


Figure 5. Scanning electron microscopic image shows cracks in cement paste.

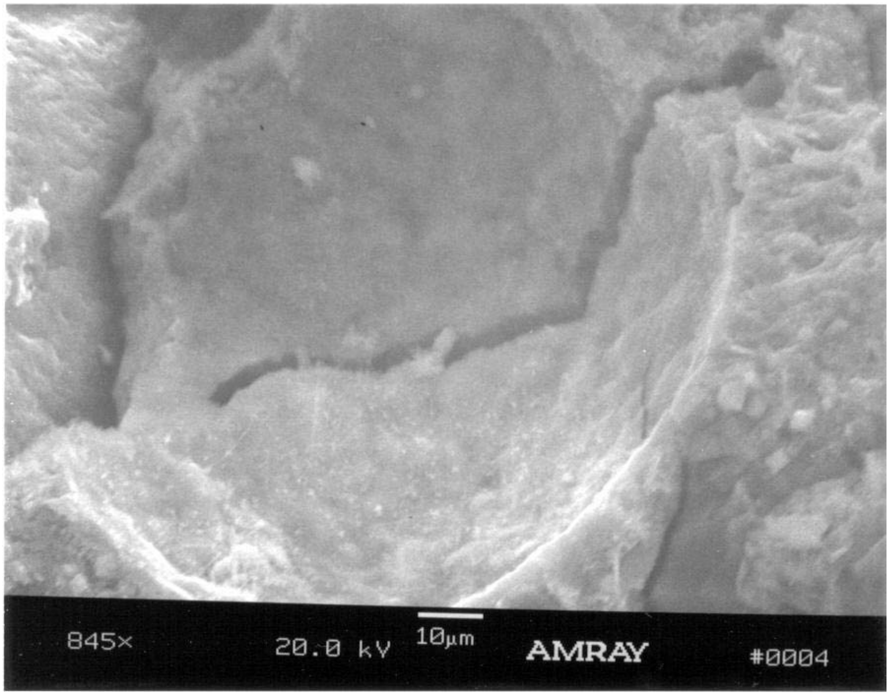


Figure 6. Scanning electron microscopic image shows details of cracking in an air void.

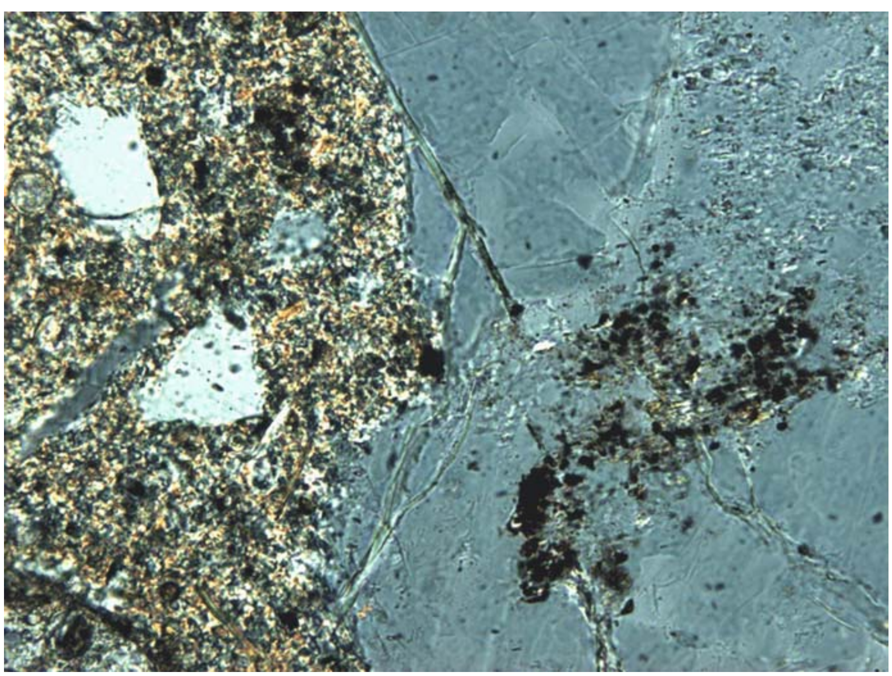


Figure 7. Possible alkali-silica reaction in a quartz particle. This picture was taken from a thin section of core 2B. Width of field 0.65mm.

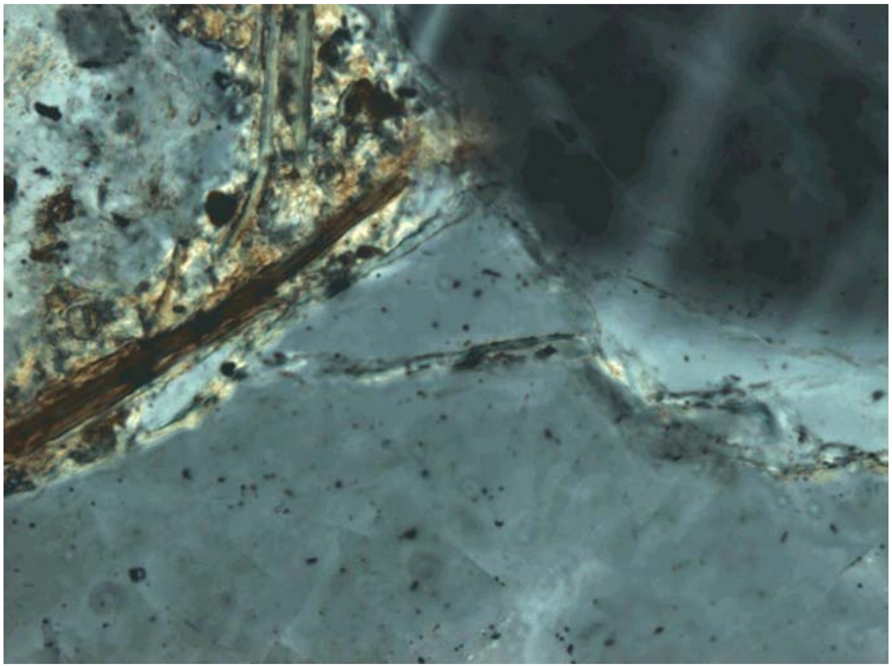


Figure 8. Cracking in a quartz particle due to possible alkali-silica reaction. This picture was taken from a thin section. Width of field 0.33mm.

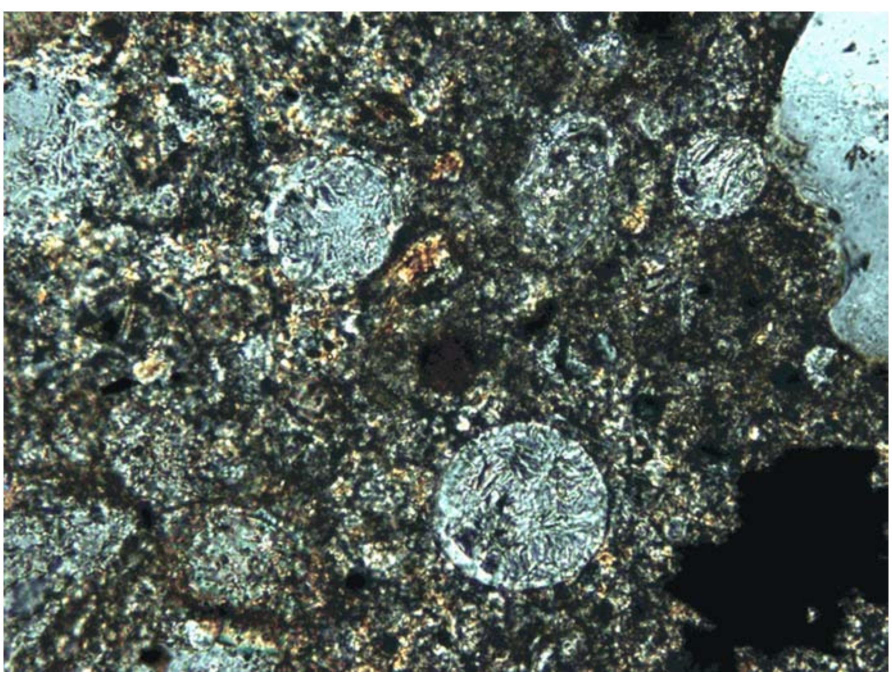


Figure 9. Ettringite crystals formed in voids. This picture was taken from a thin section of the top portion of core 2B. Width of field 0.33mm.

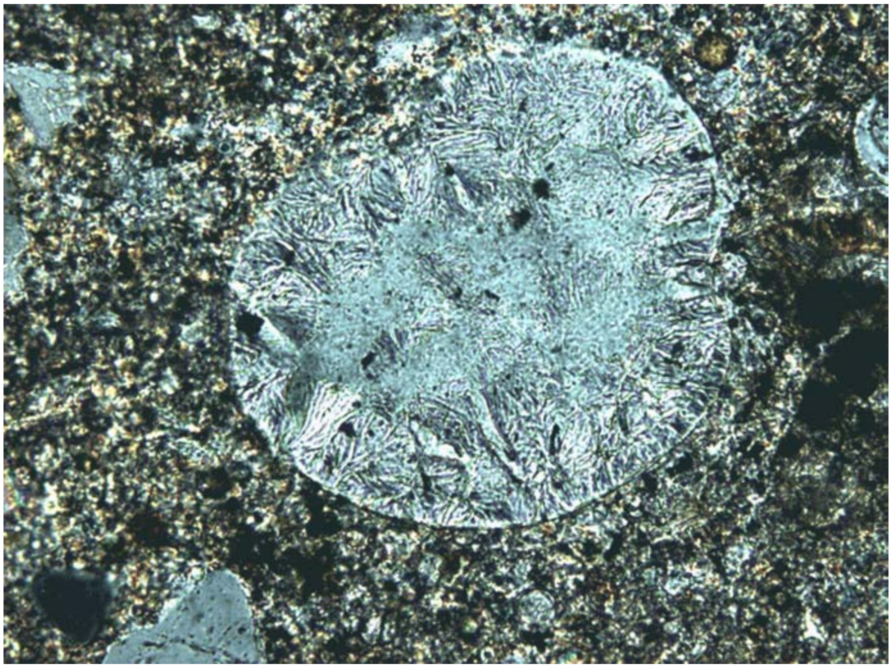


Figure 10. Ettringite partially filled in a void. This picture was taken from a thin section of core 2B. Width of field 0.165mm.

Appendix

A picture provided by Wisconsin Department of Transportation.